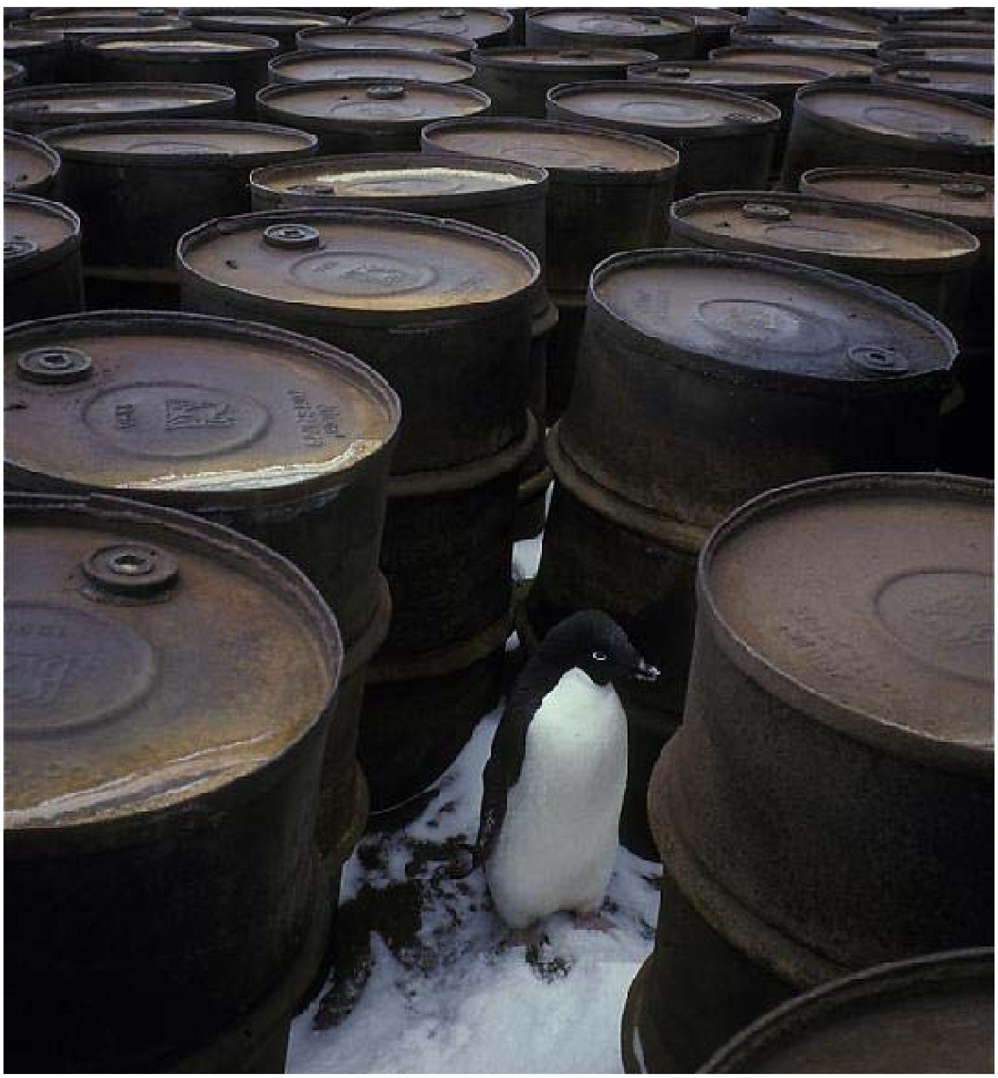
Post Graduate Certificate in Antarctic Studies: ANTA504

An Investigation into Fuel Utilisation and Energy Generation in Antarctica



Anna Mason
Student ID: 75606998

Table of Contents

Executive Summary

Fossil fuels are the predominant source of energy in Antarctica. Most Antarctic stations, including Scott Base, are powered by conventional generator units and diesel boilers.

In addition to the atmospheric pollution produced by the burning of fossil fuels, there are a number of environmental risks associated with transporting, distributing and storing fuels in the Antarctic. Fuel usage is also becoming increasingly expensive as fuel prices and transportation costs continue to increase.

Energy efficiency practices can help reduce fuel usage but serious reductions can only really be achieved through the use of renewable energy. The potential for renewable energy use in Antarctica is high, but further technological advancements are needed to make large-scale renewable energy generation more practical for the Antarctic environment.

Renewable sources such as wind and solar radiation, when used in combination with conventional energy generation, can significantly reduce a station's energy requirements. For small-scale applications out in the field, renewable energy can sometimes provide almost all of the energy needs.

Successful application of renewable energy on a large scale has been achieved by the wind farm at Australia's Mawson station, following a long investigation process. The success of this application will hopefully encourage other Antarctic Treaty Nations to invest more time and money in renewable energy research.

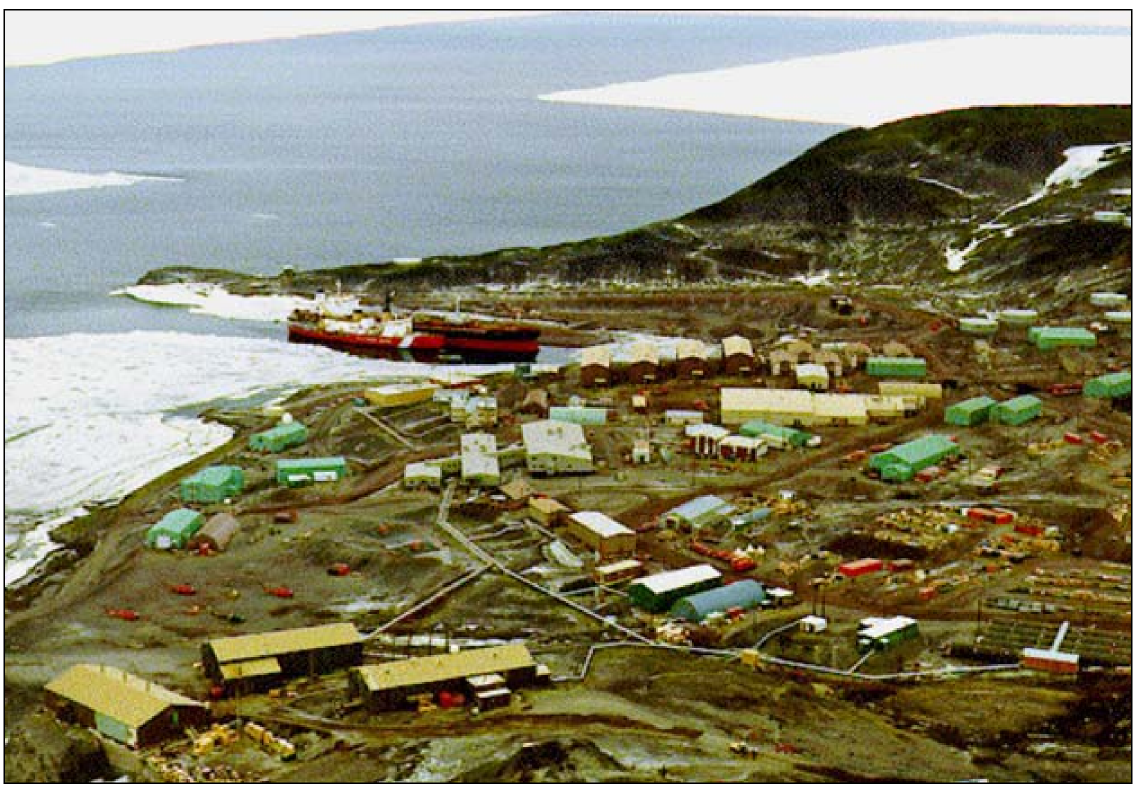


Figure 1: Icebreaker and supply ship docked at McMurdo ice wharf in Winter Quarters Bay (USAP, 2005)

Introduction

Energy generation and fuel utilisation are important global issues. The burning of fossil fuels for energy generation releases greenhouse gases into the atmosphere and ice cores from Antarctica show that the current atmospheric levels of greenhouse gases are higher than at any other time over the past 400,000 years. It is difficult to predict how the Earth's climate will react to these high levels of greenhouse gases, but global warming already appears to be evident in certain areas.

Fossil fuels provide a number of operational needs in Antarctica, including power generation and fuelling of vehicles and aircraft. New Zealand's main research facility, Scott Base, is currently completely dependent on fossil fuels for station and field camp electricity and heating, and for running the base vehicles.

The Antarctic environment is fragile and very vulnerable to human impact. In addition to the atmospheric pollution caused by the burning of fossil fuels, there are serious environmental risks involved with transporting, transferring and storing fuels in the Antarctic. The spillage of fuels resulting from potential equipment failure, accidental damage or human error can significantly threaten the Antarctic environment.

Unique problems are presented when shipping fuel to Antarctica due to its isolated geographical location. These re-supply issues, in combination with the fluctuating price of fossil fuels, are making it increasingly expensive to purchase fuels for Antarctic use.

All of these issues indicate that fossil fuels are not practical as long term primary energy sources in Antarctica. Most Antarctic Treaty nations, including New Zealand, are investigating the means to reduce, or even eliminate, their dependency on fossil fuels through reductions in energy load, improvements in energy efficiency and the incorporation of renewable energy generation.

This study investigates a number of themes relating to fuel utilisation and energy generation in Antarctica, starting with an outline of the operations involved with supplying fuel to the Ross Sea region of Antarctica. This includes a discussion of future fuel re-supply options, as recent re-supply problems have highlighted issues with the existing system.

The Scott Base fuel usage and energy supply is of great importance to the continuing occupation of the base. This report analyses the current energy and fuel practices at Scott Base, including the distribution of annual and monthly fuel usage. To complete this investigation, the costs associated with Scott Base's fuel usage are discussed with reference to the factors influencing these costs.

A summary of the issues related to fossil fuel usage in Antarctica is given, leading to an investigation into how fuel usage can be reduced; namely through the incorporation of energy efficiency principles and the use of renewable energy. The most suitable renewable energy sources for Antarctica are identified, and the ways in which these sources can be captured and utilised in the harsh Antarctic environment are discussed. To conclude this investigation, a case study of the large-scale wind farm at Australia's Mawson station is made, assessing how successful this implementation of renewable energy is from an energy generation, environmental impact and cost perspective.

Antarctic Fuel Re-Supply Operations

Antarctica is a high-risk, high-cost environment and the success of any Antarctic programme depends upon a logistics system that delivers support when and where it is needed. As most activities in Antarctica depend on fuel in one way or another, fuel re-supply is an area of great importance. In this study, re-supply operations within the Ross Island region of Antarctica are the main consideration, although re-supply of the South Pole Station will be mentioned.

McMurdo Station is the largest US base of operations in the Antarctic, located on Ross Island in the southern edge of the Ross Sea. The United States Antarctic Program (USAP) has a centric re-supply system where all materials, fuel and personnel transit by sea and air through McMurdo Station en-route to science and support operations located at McMurdo Station, the South Pole Station, or at field sites.

McMurdo station accommodates approximately 1,000 staff in summer and 200 staff in winter. These USAP scientific and support staff depend upon the annual delivery of 25,000,000kg of fuel to McMurdo Station via ship for use either at McMurdo Station itself or for trans-shipment to the South Pole Station, Scott Base, and remote field sites (NSF, 2005). Antarctica New Zealand purchases the fuel needed to run Scott Base directly from McMurdo Station so is very reliant on the annual USAP fuel delivery.

The McMurdo region was historically used by USAP and pre-IGY[1] explorers and researchers because it is located close to the 1910-1913 Scott Expedition base camp, considered to be one of the most southern sea-accessible points in the Antarctic. McMurdo Station is still accessible by sea today, but only for a relatively short period of the year, and during this period the sea channels can sometimes still be blocked by residual first-year sea ice, fast ice, and hard multi-year ice (refer Figure 2).

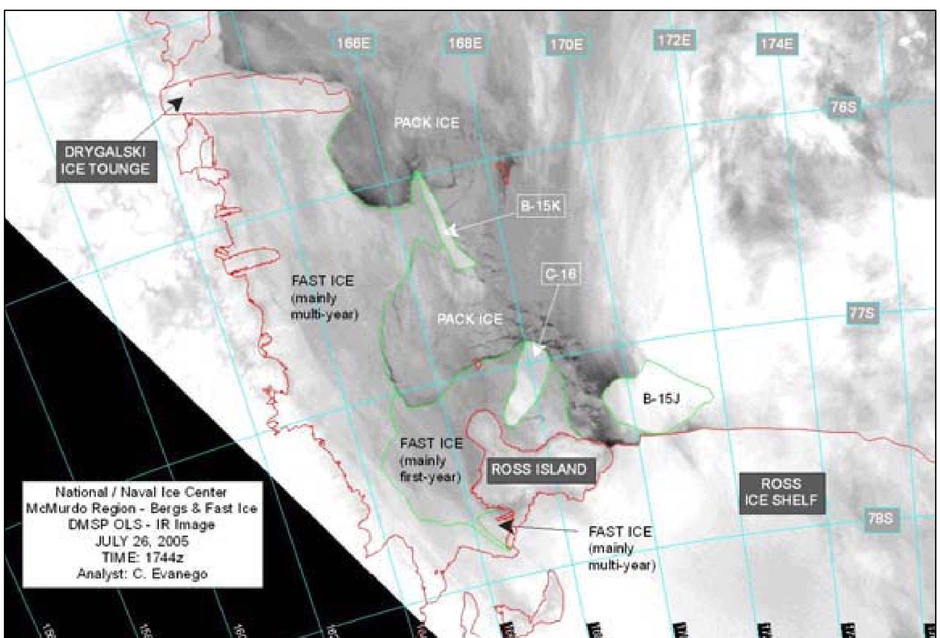


Figure 2: Satellite photo of the South-Western Ross Sea, July 26th 2005, showing sea ice, large icebergs, and fast ice (NSF, 2005)

[1] IGY refers to the International Geophysical Year of 1957-58.

Each season, a channel must be broken through the ice that has formed to allow re-supply vessels wharf-side access to McMurdo Station. The increase in ice cover over recent years means that two Polar class icebreaking vessels are needed to open a shipping channel (refer Figure 3) through the ice to McMurdo Station.

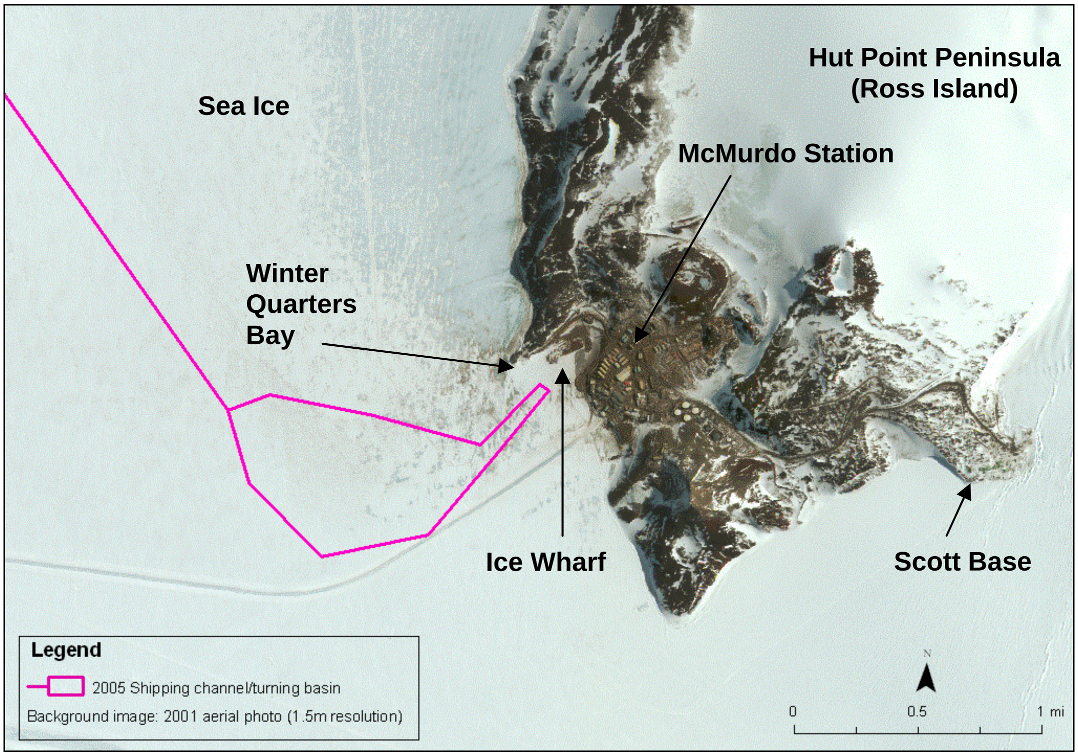


Figure 3: McMurdo Station region, showing 2005 shipping channel and turning basin (NSF, 2005)

The U.S. Coast Guard (USCG) has opened the channel for many decades but is finding it increasingly difficult and costly as its two Polar class vessels are within a few years of their estimated 30-year lifetime (NSF, 2005). Additionally, heavy ice conditions over the past four years have greatly increased the ice-breaking burden needed to open the channel for cargo and tanker ships.

During the 2004/05 season, the National Science Foundation (NSF) chartered the Russian icebreaker *Krasin* to assist the USCG's icebreaker *Polar Star* in escorting the U.S. Navy ice-strengthened fuel tanker *USNS Paul Buck* (33,093 tons, 187.5m/21.2m) and the ice-strengthened freighter *American Tern* (17,350 tons, 158.8m/23.16m) to the ice wharf at McMurdo Sound. In January 2005 of this trip, the *Polar Star* developed a serious leak. To ensure she was seaworthy for the 2005/06 season, the National Science Foundation Office of Polar Programs (OPP) gave the USCG an additional $9.2 million (NSF, 2005). This is just one example of the extra costs required to keep the USCG icebreaking vessels sea-worthy.

Typically, the ice breakers arrive at the McMurdo ice edge on or about December 31 each season and have an anticipated departure date of mid-February the following year (6-8 weeks after arrival).

The tanker carrying the USAP's annual fuel supply is expected at the McMurdo ice edge around mid-January each year. McMurdo Station is currently served by an ice wharf extending a small distance offshore in Winter Quarters Bay (see Figure 3). On docking at the ice wharf, fuel hoses are attached to the tanker and the cargo is pumped up to the fuel tank farm at McMurdo Station.

Figure 4: Tanker *USNS Lawrence H. Gianella* off-loading fuel at McMurdo ice pier (NSF, 2005)

The fuel tanker departs shortly after completion of discharge. In the 2004/05 season, the *Paul Buck* unloaded about 8 million gallons of fuel in 48 hours and left McMurdo on 31st of January 2005 (NSF, 2005). From McMurdo, the fuel is used directly at McMurdo Station or is transported by plane to the South Pole Station or USAP's various remote field locations. With respect to Scott Base's fuel supply, Scott Base personnel collect the fuel directly from McMurdo Station and transport it back to Scott Base using a 7,000 litre tank mounted on the back of a flat deck truck (Antarctica New Zealand, 2006).

If access to the ice wharf is not possible for reasons such as ice conditions being too difficult for the icebreakers, iceberg blockage of the immediate McMurdo Station area, or mechanical failure of the icebreakers, alternative sites and fuel discharge methods must be considered. In 2003, a tanker could not reach the McMurdo ice wharf so fuel was pumped from the vessel to the tank farm via hoses laid over the ice, an operation which took approximately 17 days (6 days set-up, 4.5 days pumping, and 6 days breakdown) (NSF, 2005).

Re-supply operations over long stretches of sea ice (as occurred in 2003) pose a greater environmental risk from a fuel spillage, especially with the large size of the McMurdo Station annual re-supply as it takes longer to discharge the fuel and the repeated exposure increases the risk. The changeable stability and weather response of the sea ice also significantly increases operational delays and hazards. All of these factors result in increased re-supply costs.

Future of USAP Re-Supply Operations

The current USAP re-supply system is no longer practical. As mentioned previously, the U.S. Coast Guard icebreakers are nearing the end of their lifetime and no other U.S. vessels have the icebreaking capacity required. This, in combination with the recent severe south-western Ross Sea ice conditions, makes the dependence upon the annual delivery of fuel and cargo by ship to the hub at McMurdo Station very risky.

The recent presence of the B-15A iceberg in the Ross Sea highlights the vulnerability of the entire operation. In March 2000, an enormous iceberg named B-15 calved from the Ross Ice Shelf and major pieces of it drifted and partially blocked sea access to McMurdo Station. Although a sea route was available, it filled with sea ice and transformed the previous 35±18km annual break-in through mostly first year ice, to as much as 135km (NSF, 2005). This greatly increased the icebreaking burden on the USCG Polar class icebreakers, as well as highlighting that future iceberg movement, from B-15A or other similar size icebergs, could completely block sea access to McMurdo Station. Missing one year's delivery of fuel or supplies would be extremely distressing to the USAP as well as to Antarctica New Zealand, causing little to happen except survival and subsistence.

Recognising this situation, the National Science Foundation Office of Polar Programs (OPP) began an internal investigation in 2004 of several long-term re-supply alternatives for the USAP's McMurdo and South Pole stations. In carrying out this investigation, the OPP Advisory Subcommittee was asked to take into full consideration the potential impacts of alternative logistics scenarios on present and future scientific programs, as well as the potential impacts on safety, environmental protection, reliability, cost and timelines (OPP, 2005).

The principal recommendations of this study were:

1. To develop a comprehensive systems approach to Antarctic icebreaking so the risk existing in the current system is removed, and to reduce operating, maintenance and fuel costs.

    - In the short term, commercial icebreakers should be used (as occurred in 2004/05), backed up by USCG icebreakers, if required. This ensures the USCG vessels are maintained economically and at low risk, while the other icebreakers take some of the load, and wear and tear.

    - In the long term, a new McMurdo-capable icebreaker may be required. The new icebreaker should allow for longer field seasons, increased maintenance in the field and more efficient use overall. High priority should also be given to vessel reliability, ability to carry out Antarctic missions without refueling within the Antarctic (icebreaker refueling uses around 25% of the fuel delivered to McMurdo each year – eliminating refueling will potentially release an extra 25% of fuel, making it available to other USAP priorities), and overall economy of operation.

2. In response to the immediate risk posed by the deteriorating condition of the Polar class icebreakers, and to other areas of risk faced by the seaborne re-supply of McMurdo Station, a system needs to be developed to allow for continued support at and from the McMurdo and South Pole stations in the event of one missed annual fuel re-supply.

   It is recommended that additional fuel storage capacity is built at McMurdo Station and that fuel reserves are built up to allow for one missed annual fuel delivery. Following a missed year, the total fuel consumption at and through McMurdo Station could be reduced to some extent by:

   - Reducing the number of support personnel operating out of McMurdo Station, including transferring support functions off the continent.
   - Reducing or even eliminating the direct dependence of the South Pole Station fuel re-supply on McMurdo Station.
   - Reducing or even eliminating icebreaker refueling.

The Subcommittee proposes that changes to the South Pole Station supply chain logistics will significantly reduce, and possibly eliminate, the risk of operating all logistics through McMurdo Station. To this end, it recommends the following changes to the South Pole Station re-supply:

1. Construct a runway for wheeled-aircraft capable of landing heavy-lift cargo aircraft at the South Pole Station to allow more efficient re-supply of cargo, fuel and personnel from McMurdo.

2. Continue development of the McMurdo – South Pole overland traverse route to enable alternative re-supply of the South Pole Station.

Figure 5: USCG icebreaker *Polar Star* (left) and Navy tanker *USNS Paul Buck* at McMurdo ice wharf, background shows Russian icebreaker *Krasin* (centre) (NSF, 2005)

Scott Base Energy System

Scott Base is New Zealand's main scientific research base in Antarctica, located on the southern end of Hut Point Peninsula in McMurdo Sound. The base has been continually inhabited since 1957 and currently accommodates up to 70-80 people during the summer months and 10-15 people over the winter months. The Scott Base energy system supports the research activities and living conditions of these base personnel.

Scott Base is composed of separate stages and each stage is numbered according to their completed construction date.

Stage Number	Description
1	Hut, Smoker's Hut
2	Powerhouse, including RO Plant
3A	Staff Accommodation, Ablutions
3B	Bar/Dining/Kitchen, Swamp
4	Administration
5	Hatherton Lab
6	Workshops, Powerhouse
7	Garage, Cold Area
8	Ablutions, Laundry, Drying room
9	Wastewater Treatment Plant
10	New Warm Store

Table 1: Scott Base Stages

Scott Base Electrical and Thermal Power Production

The main component of the Scott Base energy system is the power generation plant in the Stage 2 Powerhouse. It consists of two diesel electric Caterpillar generators (up to 200kW electrical, 110kW thermal, and 65% efficient) and provides all of the electrical and thermal requirements of the base. Only one of the generator units is run at a time, with the other on constant standby.

Figure 6: Generator 1 and 2 in the Stage 2 Powerhouse (Hume, 2005)

Marine manifolds, running through heat exchangers and exhaust heat exchangers, recover waste thermal heat from the generators. This recovered heat is carried through the base via a heating loop (an 80mm steel pipe), and this is the main heating source of the base. Once the heating loop leaves the Stage 2 Powerhouse, it splits into two, with one loop going to the lower base (Stages 6 and 7) and the other going to the upper base (Stages 1, 3, 4, 5, 8 and 9). To provide additional heating, Air Handler Units (AHUs), hot water heaters and radiator-type heaters feed off the loop at each stage. The heating for the new warm store (Stage 10) is provided by a stand-alone diesel fired system.

Two diesel fired boilers (rated at 98kW each) add extra heat to the heating loop, when required, ensuring the base is maintained at a constant 18-20°C even in the middle of winter. Two electric water heaters exist for this purpose also but these have not been used since 2003 in an effort to reduce the electrical loading on the base (Hume, 2005).

The Stage 6 Powerhouse contains a backup generator and two further boilers (rated at 73kW each). This generator only runs around 5% of the time as it is less efficient than the Stage 2 generator sets and the marine manifold heat exchanger does not have an exhaust heat exchanger.

Figure 7: Stage 4 AHU Heating Loop (Hume, 2005)

Scott Base Energy Loads

The average electrical load of Scott Base has been measured to be 137kW (Hume, 2005), with the vehicle hitching rails (used to prevent cold damage to internal vehicle components) accounting for up to 20% of the electrical power produced. The maximum electrical load occurs over winter, near the generator's capacity of 225kW (Hume *et al.*, 2004) due to the higher heating and lighting demand.

The approximate total thermal load has been measured to be 147kW, with the Stage 2 Reverse Osmosis (RO) plant making up over 27% of the thermal load of Scott Base (Hume, 2005).

The average total energy load at present can therefore be estimated as 284kW.

Scott Base Fuel Usage

Scott Base Fuels

Scott Base is currently completely dependent on the burning of fossil fuels to provide energy for station electricity and heating, for electrical generation in the field and for running vehicles. AN8 and Mogas are the two types of fuel used at present.

AN8 is an aviation kerosene and is the primary fuel at Scott Base, used for running the power generation plant and the heavy diesel-powered vehicles. AN8 is also used by the aircraft flying to and from Antarctica, and by aircraft within Antarctica such as helicopters and Twin Otters.

Scott Base has a maximum AN8 storage capacity of 56,000 litres. The tank is double contained and is divided into two separate compartments of 28,000 litres each. Only one of the compartments is used at a time, with the other kept in reserve. This design ensures fuel will be contained in the event of a fuel spill and also allows for snow, ice or water accumulation (COMNAP, 1992). The storage tank is refuelled approximately every 20 days using fuel purchased directly from the USAP's McMurdo Station (Antarctica New Zealand, 2006).

Mogas is a low octane unleaded petrol with an antifreeze additive, used in the base vehicles and portable generators. Antarctica New Zealand only stores around 2,000 litres of Mogas at any time (Antarctica New Zealand, 2006).

Electrical Energy Production and Fuel Usage

The Scott Base annual electrical production from 1999 to 2005 is shown in Figure 8.

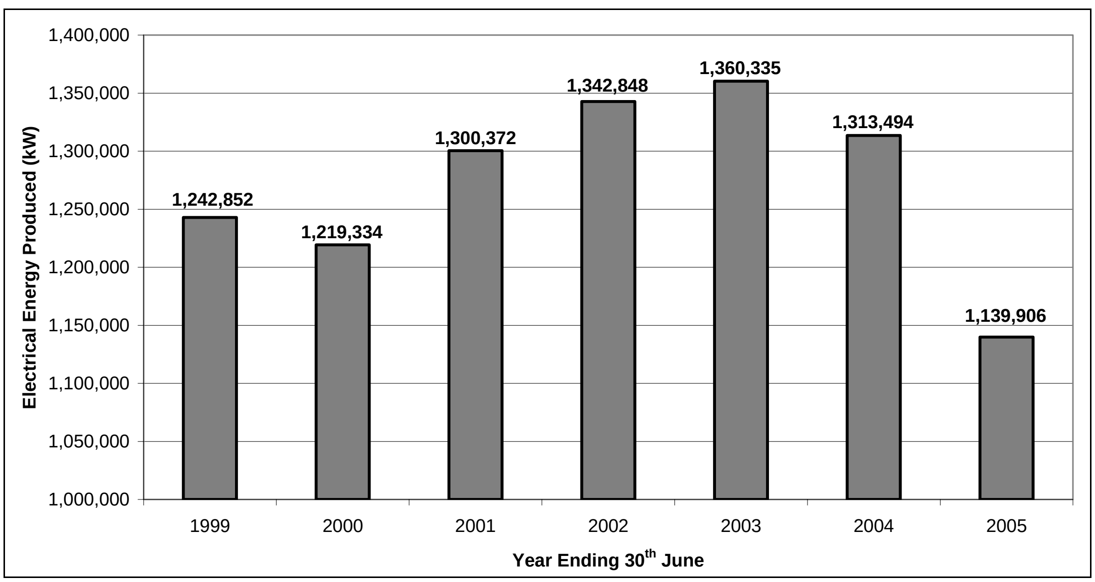


Figure 8: Scott Base Annual Electrical Production

Production for the period ending 30th June 2005 was 1,139,906kW, almost 174,000kW less than the production for the same period the previous year (equating to a 13% decrease), and the lowest ever recorded (Antarctica New Zealand, 2005). This decrease is due to the implementation of energy efficiency initiatives, discussed later in this report.

The Scott Base annual generator fuel usage from 1999 – 2005 is shown in Figure 9.

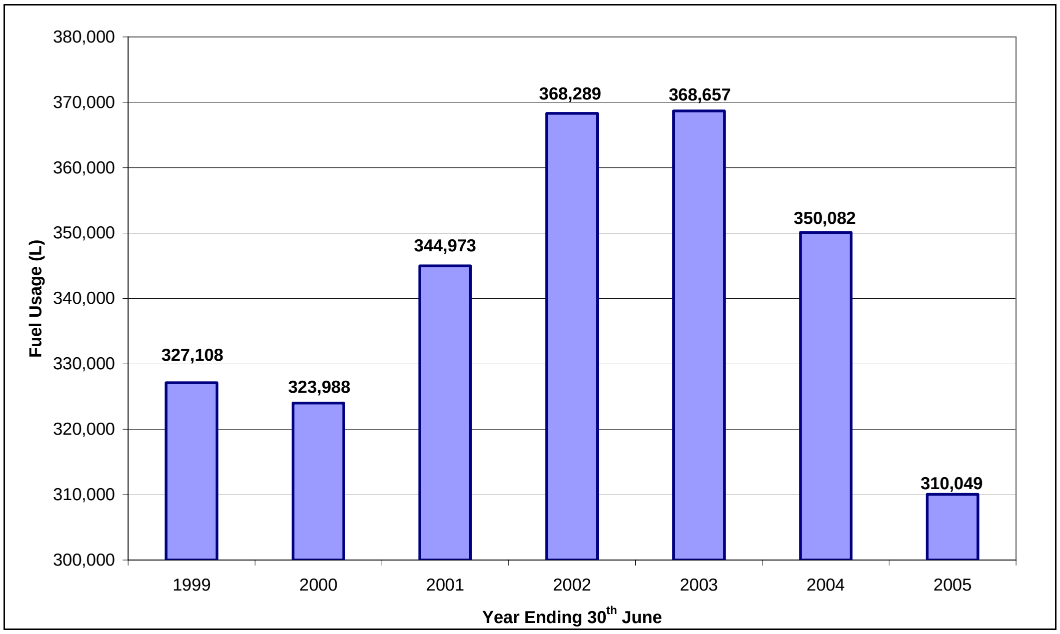


Figure 9: Scott Base Annual Generator Fuel Usage

This graph follows the same trend as Figure 8, with fuel usage for the period ending 30th June 2005 (310,049 litres) being significantly less than any other year's usage. This illustrates the direct relationship between electrical production and fuel usage.

Thermal Energy Fuel Usage

As discussed previously, two 98kW diesel fired boilers within the Stage 2 Powerhouse and two 73kW boilers within the Stage 6 Powerhouse contribute to the Scott Base heating. Figure 10 shows the annual amount of AN8 fuel used for all four units.

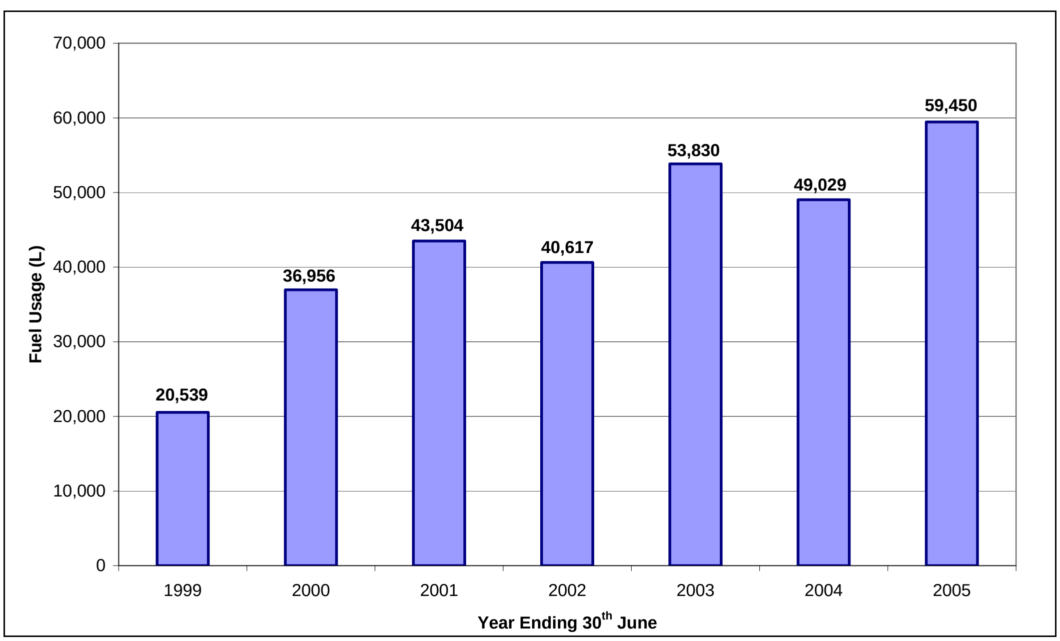


Figure 10: Scott Base Annual Boiler Fuel Usage

This graph indicates that boiler fuel usage has increased over the 2004-05 year ending 30th June, with a record high of 59,450 litres. The reasons for this increase are not certain, but the rise since 2002 can be partly attributed to the switching off of the main heating loop's supplementary electric heating (Antarctica New Zealand, 2005).

Combined Energy Fuel Usage

Figure 11 shows the Scott Base annual combined electrical and thermal energy fuel usage over 1999 – 2005.

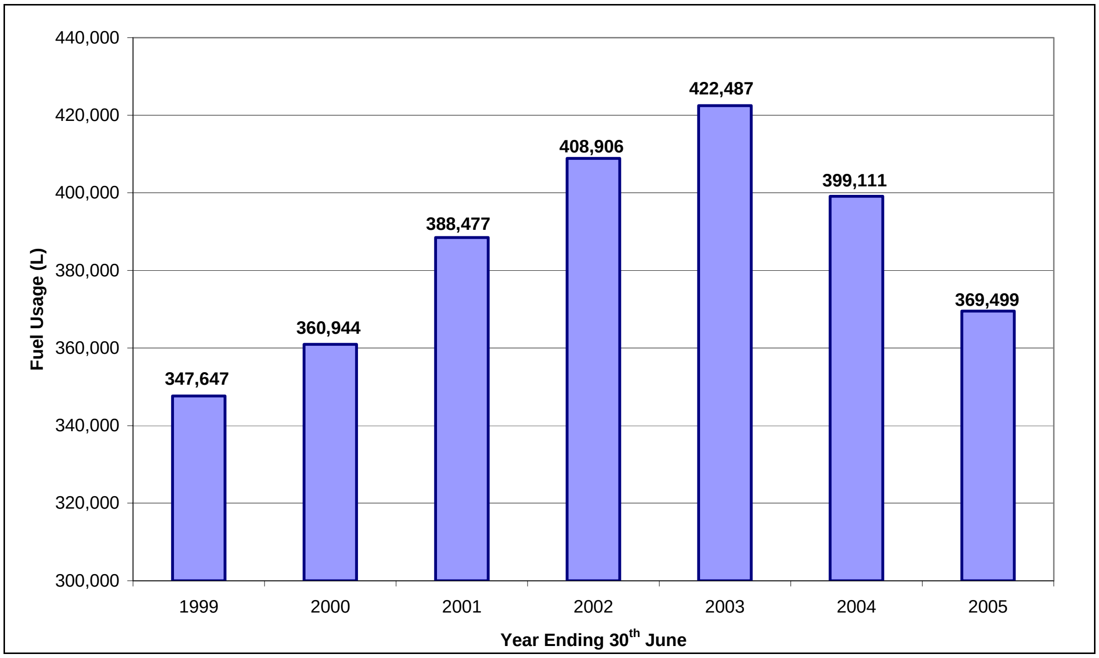


Figure 11: Scott Base Annual Energy Production Fuel Usage

This graph illustrates that although the thermal energy (boiler) fuel usage is increasing (as shown in Figure 10), the decrease in electrical energy (generator) fuel usage is driving down the total fuel usage. Obviously, electrical energy is the predominant fuel consumer at Scott Base. The 2005 figure of 369,499 litres is significantly lower than any usage since 1999/2000, indicating that reductions in electrical energy are being made, despite the base increasing in size over this time. The factors influencing this decrease are discussed within the Scott Base Energy Efficiency section of this report.

It should be noted that the newly constructed Hillary Field Centre (HFC) will significantly increase the fuel usage of the base, possibly by 30% or more (Antarctica New Zealand, 2005). Since early February 2005, a temporary heating supply has been set up for the HFC and it is estimated that 9,000 litres of AN8 has been used in this system to 30th June 2005 (Antarctica New Zealand, 2005). It is not possible to give accurate estimates on the total increases in fuel and electricity associated with the HFC at this stage.

Vehicle and Field Support Fuel Usage

Field support refers to all activities in the local region which are deployed from Scott Base, as opposed to base support which refers to all activities carried out while operating and maintaining the facilities at Scott Base.

The Scott Base vehicles are classed as either field support or base support, as follows.

Field Support Vehicles	Base Support Vehicles
Caterpillar D6H*	Toyota fleet
Caterpillar D5	Isuzu truck
Skidoos	Caterpillar 926E Loader
Hagglunds	Caterpillar D8
Pisten Bullys	Caterpillar D4G[+]
Asvs	-

Table 2: Scott Base Classifications (Rigarlsford, 2003)

* Caterpillar D6H also helps with clearing snow from the base

[+] Caterpillar D4G also participates in event deployment

Mogas is used in base vehicles and portable field generators and AN8 is used by both base and field vehicles, and by field events for heating and field generators. The amount of Mogas purchased and the amount of AN8 fuel pumped through the Scott Base vehicle bowser gives an estimation of the total vehicle and field support fuel usage. The total Mogas purchase amount can be used to represent the actual Mogas usage as Scott Base has limited Mogas storage (2,000 litres).

The Mogas and AN8 meters do not distinguish between fuel used for vehicles (base support or field support), and fuel used for field support (drummed fuel), so vehicle and field support fuel usage is grouped together.

Figure 12 shows the annual vehicle and field support fuel usage over 1999 – 2005.

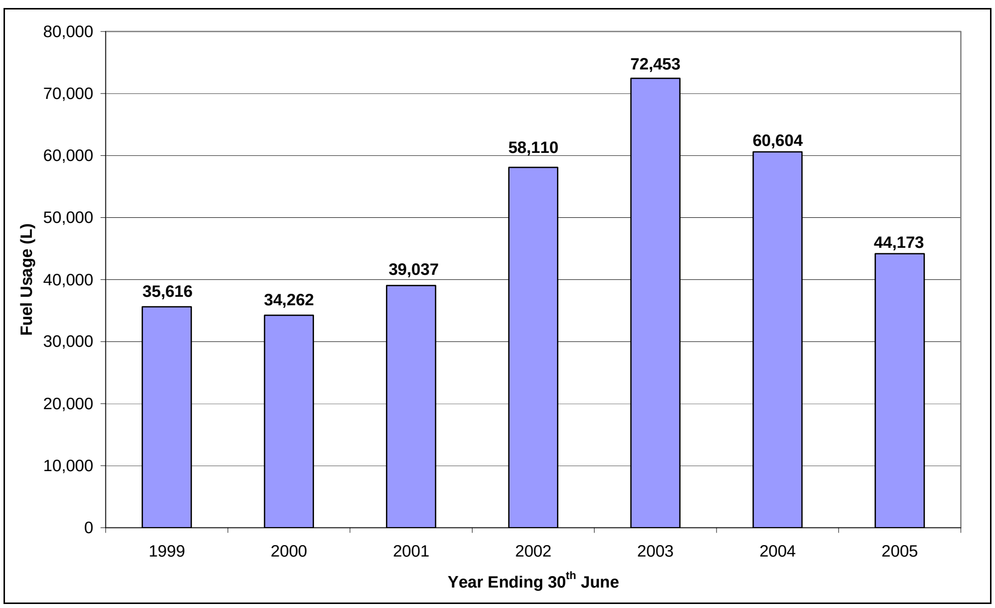


Figure 12: Scott Base Annual Vehicle and Field Support Fuel Usage

The significant increase in the 2002/03 season (a 25% increase from 2001/02) is due to the ANDRILL project which used 3,400 litres of fuel alone. The 2004/05 value includes the HFC fuel usage and it is likely that this has contributed to the slightly higher 2004/05 fuel usage levels, although they are still lower than those in 2002/03 and 2003/04. The HFC usage will be incorporated into the boiler fuel consumption from September 2005 onwards (i.e. from completion of the building) (Antarctica New Zealand, 2005).

Scott Base Fuel Distribution

The Scott Base fuel usage can be separated into the following three categories:

- Generators (to produce electrical energy)
- Boilers (to produce thermal energy)
- Vehicles and Field Support (to run vehicles and field generators/heating)

The following sections interpret how the Scott Base fuel usage is distributed amongst these categories, by year and by month.

Annual Fuel Usage and Distribution

Figure 13 outlines the annual total fuel usage for 1999 - 2005, and the percentage distribution of this usage by generators, boilers, and vehicles and field support.

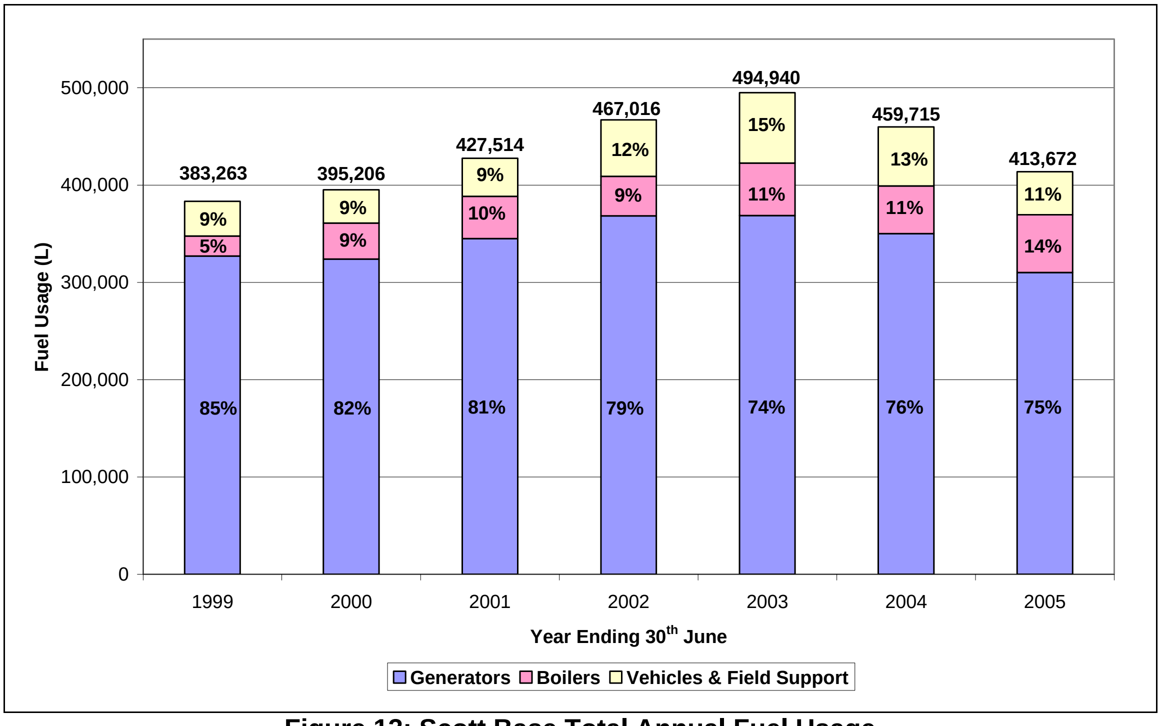


Figure 13: Scott Base Total Annual Fuel Usage

This figure follows the same trend as the total energy fuel usage (Figure 11), with the overall fuel usage peaking in 2002/03 and decreasing in the years following. The fuel usage in 2004/05 is at its lowest since 1999/2000.

It is obvious from this figure that generators consume the greatest amount of fuel, with generator fuel usage ranging from 74% to 88% of the total fuel usage since 1999. Vehicle and field support and boilers appear to have very similar fuel requirements. This highlights that if any significant reductions in fuel usage are to be made at Scott Base, the fuel usage of the generators (i.e. the electrical load) should be addressed first, although reductions in all areas should be considered.

Monthly Fuel Usage and Distribution

The two main influences on the Scott Base energy consumption, and hence the fuel usage, throughout the year are the level of activity on the base (highest in summer), and the lighting and thermal requirements (highest in winter).

The monthly fuel usage for the 2004/05 season and the distribution of this usage by generators, boilers, and vehicles and field support is shown in Figure 14.

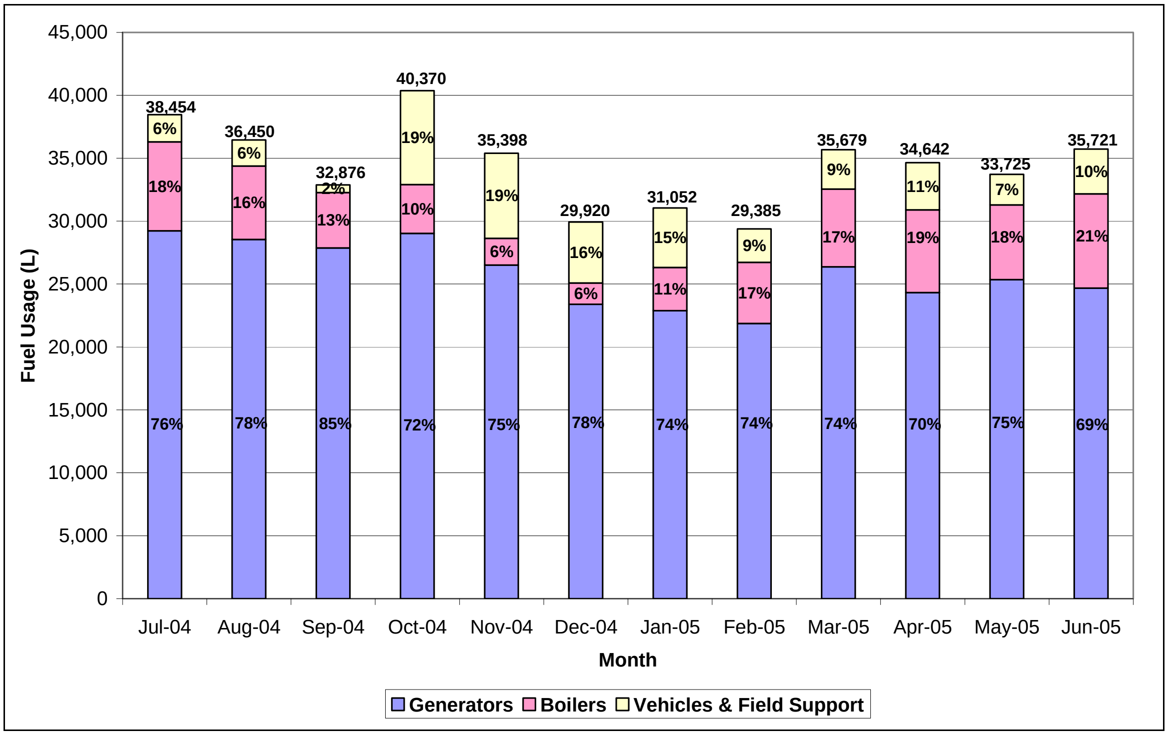


Figure 14: Scott Base Monthly Fuel Usage

This figure shows that fuel usage was at its lowest during the height of the summer i.e. over the months of December, January and February (92,920, 31,052 and 29,385 litres respectively). This suggests that although the level of base activity is at its highest over this time, the reduced lighting and thermal requirements have a more significant influence on the base energy requirements, resulting in a decrease in overall fuel usage.

Although the overall fuel usage was reasonably high at the beginning of summer, it is possible to see that the boiler fuel usage was at its lowest from November through to January, with the maximum percentage distribution of boiler fuel usage over this time being only 11%. This indicates that through the summer months (November through to March) the boilers are not used as often as the thermal energy recovered from the generator sets is more than adequate to provide the base's heating requirements. The increase in boiler fuel usage in February and March suggests that the temperatures were lower than average, resulting in a need for extra heating.

More energy, and more fuel, is required during the winter months due to the necessity for extra heating and lighting. Figure 14 illustrates this, with the combined boiler and generator fuel usage being higher in winter than summer. Figure 14 also indicates that this extra energy is provided mainly through the use of the diesel fired boilers (boiler fuel usage accounts for 21% of the total fuel used in June 05 and total generator usage does not vary greatly from summer to winter). However, both the electrical and thermal energy recovered from the generator sets are increased during the winter months (Hume *et al*., 2004).

The vehicles and field support fuel usage is at its highest during the summer months which is to be expected as the greatest level of activity occurs during the daylight months. The sharp rise in vehicles and field support fuel usage from September (609 litres) to October (7,472 litres) indicates the arrival of daylight, an increase in base personnel and the beginning of the field event season.

Antarctic Fuel Costs

The cost of fuel in Antarctica is influenced by a number of factors including the original fuel price, costs associated with fuel re-supply and exchange rate fluctuations. These factors are discussed further in the following sections.

Fuel Price Volatility

Fossil fuel prices are extremely volatile and are affected by many factors, primarily supply and demand, and market speculation. These price fluctuations have a significant impact on the price Antarctica New Zealand pays for its fuel in Antarctica.

Recently, the rapid increase in world oil demand has been a major influence on the fuel price with the International Energy Agency reporting that global demand increased by 1.3% in 2005 and is expected to grow by another 2.2% in 2006 (International Energy Agency, 2006). The Agency attributes the increase in demand to rapid expansion in several countries, particularly China. Additionally, several oil-producing countries such as Iraq and Venezuela have experienced political unrest, in turn affecting their ability to produce at full capacity.

These supply and demand issues have raised fears of possible future fuel supply shortages, which in turn result in increased speculation in the futures markets, leading to substantial upward pressure on prices. In August 2004, Acting OPEC Secretary General Maizar Rahman estimated that speculation was adding between $10 and $15 (USD) to the oil price.

Fuel Re-Supply Costs

The initial fuel cost is a major contributor to the price of fuel in Antarctica but the actual fuel cost also includes the fuel re-supply costs (the transportation costs). Re-supply costs consist of the pro-rated charter cost of the tanker vessel bringing fuel to Antarctica and the pro-rated cost of the icebreaker(s) which open up the sea channel for the tanker.

As the charter length can vary considerably due to weather and sea ice conditions, the initial product price is sometimes the best indicator of fuel costs and may be used to determine the fuel costs in advance. Obviously this is not always realistic and may be misleading.

Up until the 2004/05 season, the price Antarctica New Zealand paid for its fuel included the cost per gallon of product, plus the charter cost of the tanker divided by the number of gallons delivered. From 2005 onwards, the fuel price will also include the cost of the ice breaker support divided by the number of gallons. As the USAP are now contracting in at least one external icebreaker per annual fuel re-supply, the actual fuel price is expected to increase significantly.

Exchange Rate Fluctuations

Fuel is a tradable good so it depends very heavily on what the exchange rate does. Even if global fuel prices stabilise, there is still the potential for Antarctica New Zealand to pay more for its fuel because of the New Zealand exchange rate.

Bennett (2006) reports that "the strength of the NZ dollar over the last year or so has provided some insulation to the economy from the impact of higher fuel prices but obviously if expectations about the currency over 2006 pan out, then that insulation is going to well and truly disappear". This obviously extends to New Zealand's interests in Antarctica as well, leading to increases in the cost of fuel required to run Scott Base if the New Zealand dollar drops as predicted.

Scott Base Fuel Costs

Scott Base is currently 100% dependent on fossil fuels for its electrical and thermal generation. This fuel dependency means that Antarctica New Zealand is also completely dependent on fuel price volatility.

Table 3 summarises the recorded energy and fuel figures for Scott Base over the 2004/05 season ending 30th June.

Variable Type	Quantity
Electrical Production	1,139,906kW
Generator Fuel Usage (AN8)	310,049L
Boiler Fuel Usage (AN8)	59,450L
Vehicle and Field Support (AN8, Mogas)	44,173L
Total Fuel Usage (AN8, Mogas)	413,672L
AN8 Purchased	417,693L (110,343 US GA[2])
Mogas Purchased	12,818L (3,386 US GA)

Table 3: Scott Base Energy and Fuel Usage 2004/05 Season

Antarctica New Zealand purchases fuel for Scott Base directly from the USAP's bulk fuel farm at McMurdo Station. For the 2004/05 season ending 30th June, Scott Base purchased 417,693 litres of AN8 and 12,818 litres of Mogas from USAP.

Figure 15: McMurdo Station Fuel Farm

Figure 16 shows the price of AN8 and Mogas over the last five financial years. These prices include the cost of the actual product and the costs associated with transporting the product to McMurdo.

[2] Using the conversion rate of 1 litre = 0.2642 U.S. gallon (TheTipsBank.com, 2006).

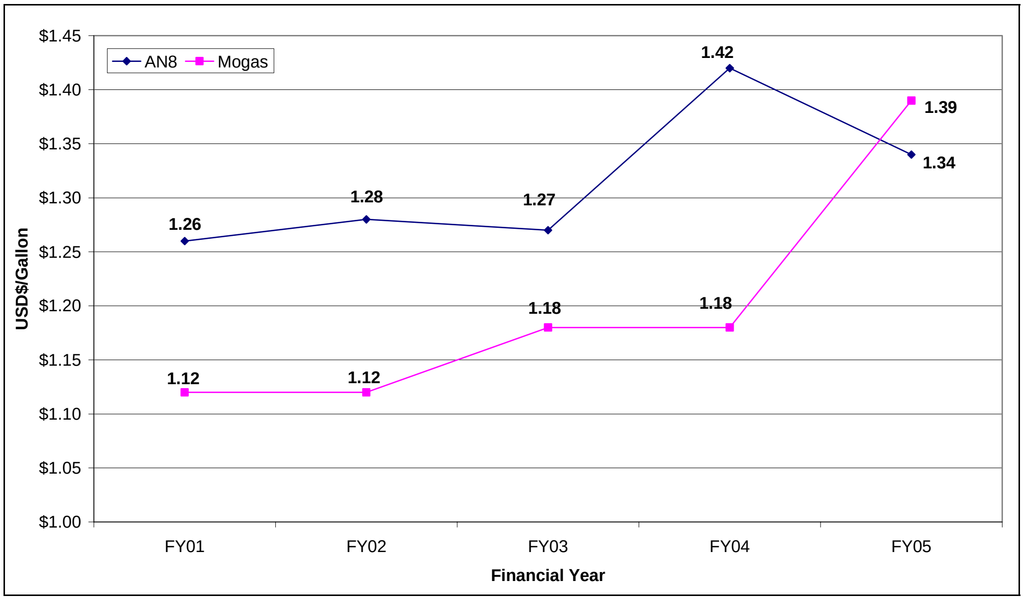


Figure 16: AN8 and Mogas Price History (Antarctica New Zealand, 2006)

This graph illustrates the fluctuating behaviour of fuel prices. The price of AN8 remained reasonably stable until FY03, at which point it rose by 12% to $1.42 (USD) in FY04. It then decreased by 6% to $1.34 (USD) in FY05. Mogas increased slowly until FY04, at which point it rose sharply to $1.39 (USD) (an 18% increase), putting it at a higher price than AN8.

To investigate the effect of these price changes on the Scott Base fuel costs, Table 4 utilises the 2004/05 Scott Base AN8 and Mogas purchase quantities and calculates the total cost using the yearly fuel prices from Figure 16.

Year	AN8 Cost (USD)	Mogas Cost (USD)	Total Cost (USD)	Total Cost (NZD)[3]
FY01	$139,032	$3,792	$142,824	$210,709
FY02	$141,239	$3,792	$145,031	$213,965
FY03	$140,135	$3,996	$144,131	$212,637
FY04	$156,687	$3,996	$160,682	$237,055
FY05	$147,859	$4,707	$152,566	$225,081

Table 4: Fuel Cost Yearly Comparison

Table 4 illustrates that changes in fuel price affect the Scott Base fuel costs significantly. Using FY01 prices and the 2004/05 fuel quantities, the total cost would be $142,824 (USD) as opposed to the FY05 cost of $152,566 (a 7% increase on FY01 costs) and FY04 cost of $160,682 (a 13% increase on FY01 costs) for the same fuel quantities.

The total combined cost rose by 11% in FY04 ($16,550 (USD)) and then fell by 5% in FY05 due to the decrease in AN8 price.

This AN8 price decrease is not expected to continue in FY06 as from 2005 the fuel price will also include the fuel re-supply icebreaker costs. The AN8 product price is also predicted to increase (Antarctica New Zealand, 2006).

[3] Using the conversion rate of 1 USD = 1.4753 NZD (XE.com, 2006)

Issues Associated with Fuel Usage in Antarctica

Fossil fuels are not practical as long term primary energy sources in Antarctica. Even if these resources could be considered inexhaustible, which obviously is not the case, there are many other detrimental effects associated with fuel usage in such a fragile environment, all of which encourage a reduction in fuel usage.

Environmental Issues

The combustion of fossil fuels releases carbon dioxide emissions and other impurities into the atmosphere. During 2002, it was calculated that Scott Base alone produced over 1,100 tonnes of carbon dioxide (CO_2) with a volume of over half a million cubic metres (Hume, 2005). In addition to the atmospheric pollution caused by the exhaust gases, there are also serious environmental risks involved with transporting, transferring and storing fuels in the Antarctic. There is a great risk of fuel spills, notably during ship-to-shore transfers which can often take place under difficult circumstances. In 2003, the USAP fuel tanker could not reach the McMurdo ice wharf and had to discharge its fuel over the sea ice, increasing the risk of a fuel spill. This is just one example of the complications that can arise.

Fortunately, there have been few major fuel spills to date in the Antarctic. The most serious spill involved the tanker *Bahia Paraiso*, an Argentine vessel which hit an unchartered shoal off the Antarctic Peninsula in January 1989. During the course of the incident, about 600,000 litres of diesel fuel and other petroleum products leaked from the hull and the spill spread to an estimated area of 30km^2 (NSF, 1995). Much of the spilled fuel was dissipated by natural actions, but the wildlife population was significantly impacted.

Figure 17: Grounded tanker *Bahia Paraiso* (NSF, 1995)

Accidental fuel spills on land in Antarctica are more frequent and mainly occur near research stations where fuel storage and refuelling of vehicles takes place. The most common accidents are pipeline ruptures or leaks in fuel storage tanks, as well as spills during transport.

Cost Issues

The cost of transporting, storing and distributing fuel in Antarctica is expensive and extremely variable. Furthermore, political and economic influences lead to severe fluctuations in price and availability of fossil fuels. These price fluctuations can have a serious impact on the budget of Antarctic programs such as Antarctica New Zealand.

Supply Issues

The complete reliance on imported fuel in Antarctica can exert pressure on logistics operations and unexpected events such as technical breakdowns or storms and heavy ice cover can threaten the closure or downgrading of station activities and field events. This can occur despite the existence of fuel reserves and depots.

An additional supply factor to consider in relation to New Zealand's interests in Antarctica is Antarctica New Zealand's dependence on US-supplied fuel. If for some reason the USAP pulled out of McMurdo or could not supply fuel to Scott Base, Scott Base would not be able to operate in its current state.

Antarctic Fuel Usage and the Future

All of these issues highlight the need to move away from the current reliance on imported and environmentally unfriendly fuels. It makes sense to incorporate energy efficiency measures at Antarctic stations and field camps, as well as seek opportunities to use renewable and alternative energy systems on both economic and environmental grounds.

Energy Efficiency in Antarctica

Energy consumption at Antarctic stations is affected by many factors such as ambient air temperature, internal temperature settings, number of people on base, water production and consumption, and general living habits of the base inhabitants.

Although many of these factors cannot be controlled, the implementation of simple energy efficiency measures can often result in significant energy and cost savings.

Energy Efficient Station Design

There are many ways in which an Antarctic station can become more energy efficient. These include optimum site orientation, temperature control, insulation, double/triple glazed windows, lighting, and energy saving office and laboratory equipment. Each of these measures could be discussed in great detail, but for the purposes of this report, the important points are outlined below.

Site orientation can have a major impact on the energy required for heating and lighting. Siting a station for maximum sun exposure during the Antarctic summer will ensure the station has the benefit of solar radiation for passive solar heating and lighting.

Heating is obviously an important factor in Antarctic station design. Heating provides a comfortable temperature for users, a satisfactory operating temperature for equipment and an ideal storage temperature for food or other supplies. It is important to satisfy these heating requirements, but *only* these requirements. Any small temperature excess can have a cascading effect, generating a large increase in heat consumption. Station temperature control can help reduce this unnecessary heat consumption.

Space heating uses a large proportion of the energy generated at an Antarctic station. Good insulation and proper securing of buildings increases the station's thermal properties and reduces the space heating (and therefore thermal energy) required. Thermal loss is largely affected by the surface area to volume ratio of a building, and fewer larger buildings rather than numerous small buildings has been shown to reduce heat loss and subsequently enhance energy efficiency (AAD, 2006). Additionally, heat escapes through windows, so increasing the number of panes of glass (i.e. double or triple-glazing) reduces the possible heat loss.

A significant proportion of the energy generated at an Antarctic station is required for lighting, especially during the long dark winter months. Lighting load can be minimised through the use of efficient lighting appliances, timers and motion detectors. Switching to energy-saving office and laboratory equipment can also help reduce the electrical load.

Energy Efficient Station Operations

Energy savings can also be made by applying energy efficiency principles to the operations within the station.

These include water conservation programs (for example, limit shower time and shorten laundry cycles), waste energy recovery techniques (use waste energy for other applications around the station), improvements to general living habits (for example, turn off lights when leaving a room and don't leave external doors open while taking off/putting on outside gear) and energy conservation training for staff.

Scott Base Energy Efficiency

Almost all of Scott Base's energy needs (and the energy needs of its associated field activities) are produced through the burning of fossil fuels. Antarctica New Zealand has a long term goal of reducing fossil fuel usage and this goal can only be achieved by reducing the energy load, improving energy efficiency and incorporating renewable energy generation into Scott Base's energy system.

The current energy efficiency of the base (defined as the output energy (thermal and electrical) divided by the input fuel energy) is considered good, with a rating of 70% (Hume, 2005). The recovery of waste heat from the generators for base heating represents a large energy saving and the cool-store type panels (comprising of polyurethane foam exterior with steel sheet facings) used in most of the base buildings provide effective and reliable thermal insulation (as cited by Grange, 2004). Windows are double or triple-glazed and doors are thick polyurethane steel clad refrigeration doors with quick release handles, helping to eliminate heat loss. To minimise heat conduction to the exterior of the building, the bolts are plastic and buildings are raised above the ground on wooden supports.

Since 2002, Antarctica New Zealand has introduced a range of energy efficiency measures around Scott Base, summarised below:

- Energy efficient lighting has been installed in sections of the base (all base lighting is expected to be energy efficient by 2006).
- Motion detector lights installed in sections of base.
- Skeleton lighting system installed in Stage 4 linkway corridor.
- Unnecessary vehicles unplugged from hitching rail over winter period.
- Hitching rail turned off over warmer summer months.
- Fresh air intake dampers on all air handlers have been closed and exhaust dampers reduced to 20%.
- Closure of hydroponics unit (considered a temporary situation while new Hillary Field Centre energy loads are established).
- Heating for TAE hut and summer labs switched off over winter period.
- Spring shutoff faucets installed in all hand basins.
- Water efficient shower heads installed.
- Main electrical appliances in kitchen converted to gas, including range (20kW), convection oven (7.2kW) and steamer (6.2kW).
- Scott Base staff trained in energy conservation practices, which are now incorporated into day-to-day life.

The Scott Base Fuel Usage section of this report illustrates that there has been a large reduction in the electricity produced for the base since 2002/03, with the 2004/04 electricity production being the lowest ever recorded (refer Figure 8). Scott Base fuel usage has also decreased significantly, with 2004/05 having the lowest fuel usage since 2000 (refer Figure 13).

These electricity and fuel savings (achieved even with increasing numbers of field events and base personnel) suggest that the recently introduced energy efficiency measures are contributing to the long term goal of reduced fuel usage. However, further improvements can still be made.

A recent energy audit by Hume (2005) identified a number of areas where improvements could be made at Scott Base. He observed that thermal losses from leakage were high around the base and recommends that significant gains could be made by mending 'leaky' doors and replacing door seals regularly. Thermal losses could also be reduced by constructing cold porches at main exits and triple-glazing all windows (Rigarlsford, 2003).

The recovery of waste heat from the generator units was determined to not be as efficient as it should be, suggesting that the exhaust heat exchangers are either undersized or blocked. Maintenance, or replacement, of the marine manifold and exhaust heat exchangers could save up to 65,000 litres to 88,000 litres of fuel per year (Hume, 2005).

Although the total plant efficiency is high, it is important to point out that a large proportion of the fuel used goes towards generation of electrical power. Since 2003/04, the vehicle hitching rail has been turned off during the warmest months. The rail accounts for up to 20% of the electrical load so turning it off reduced the electrical load significantly, and this reduction can be seen in Figure 8 (refer Scott Base Fuel Usage section). The hitching rail uses electrical energy for heating which is quite inefficient (around 38% efficiency). It is recommended that an alternative form of heating such as gas is considered (Hume, 2005).

As outlined earlier, the current fuel to electrical and thermal energy conversion efficiency at Scott Base is 70%. Substantial fuel usage would still occur if the energy system was 100% efficient, for example with the current energy demand and 100% efficiency, 265,000 litres of fuel would still be required annually (Hume, 2005). This leads to the conclusion that although energy efficiency measures will reduce fuel usage at Scott Base, the use of renewable energy will be the only means by which complete independence from fossil fuels will be achieved.

However, it should be noted that the Scott Base diesel generators provide waste heat, which is then used to heat the base. The replacement of these generators with an alternative form of energy would increase the demand for thermal energy which the alternative energy would have to provide, in order to replace the heat no longer being produced by the generators. This must be taken into account when considering energy alternatives for Scott Base.

Antarctic Alternative Energy Options

The issues associated with fossil fuel energy generation globally have lead to an increase of research into alternative energy options. The majority of alternative energy systems developed currently fall into the category of renewable energy, which involve the generation of energy from natural and renewable resources such as solar radiation, wind, waves and tides. While energy generation from each resource offers its own advantages and disadvantages, all result in a reduction in the quantity of fossil fuel used.

Antarctica New Zealand and the Electric Power Engineering Centre at the University of Canterbury are currently investigating future renewable energy alternatives for Scott Base, with the overall aim being to reduce the quantity and dependency on fossil fuels. A system used to replace the existing generators will require 155kW of power on average if a significant reduction in fossil fuel usage is to be achieved (Hume *et al*., 2004).

So what alternative energy options are suitable for use in Antarctica? Wind and solar radiation are the obvious potential sources of renewable energy, but hydrogen power is also an untapped source. How these sources can be captured and utilised in the harsh environment of Antarctica is discussed in the following sections.

Wind Energy Generation

There is great potential for wind power generation in Antarctica but few wind turbines can withstand the extreme environment. Typical average wind speeds at coastal sites range from 5 to 10m/s with a high frequency of strong winds and extreme top speeds where katabatic winds travel down the ice cap (Guichard *et al*., 1996). These strong, gusty winds and the freezing temperatures in Antarctica place enormous stresses on wind turbine rotors, causing frequent mechanical failures.

Although wind generators have been trialled since the first expeditions to Antarctica, the high failure rates as well as energy storage problems and the continuing need for complete back-up systems made wind turbines unfavourable compared to conventional generator sets and boilers. Between 1950 and 1970, most wind turbines were withdrawn from Antarctic operations, with the exception of small remote field systems. In the field, wind turbines (sometimes in combination with solar generators) have been used to operate lighting, computers, communications equipment, kitchen appliances, power tools, and laboratory equipment throughout the summer season (NSF, 2005).

Since the mid-80s, trials of larger wind turbine prototypes have taken place, with mixed results. In 1991, a vertical axis 10m diameter H rotor “HMW-56” turbine (3 blades, rated 20kW at 9m/s) was installed at the German Neumayer Station on the Ekström Ice Shelf in the north-east Weddell Sea. The turbine has a survival wind speed of 68m/s and a minimum operating temperature of -55°C and from its second year of operation it ran continuously without interruptions or breakdowns, producing an output of 40kWh/year, around 5-15% of the energy requirements of the station.

In comparison, in 1986 at Amsterdam Island (a peri-Antarctic island), a vertical axis 10m diameter Darrieus rotor “CEA30-AD10” turbine (3 blades, rated 30kW at 13.5m/s) was installed. The turbine initially worked well but continuous problems resulted in the turbine being eventually discarded (Guichard *et al*., 1996).

A small number of manufacturers have developed commercial turbines for stand-alone operation in very difficult wind conditions, and cold and/or corrosive environments. Of these commercial turbines, the Vergnet turbine is recognised to offer the highest resistance to extreme winds while still ensuring high efficiency and low maintenance requirements (Guichard *et al*., 1996). In 1995, a trial wind turbine was erected at the Australian Casey Station on the East Antarctic coast, and upgraded in 1996 to the Vergnet "GEV7.10" turbine (2 blades, rated 10kW) (AAD, 2006). The turbine operation encountered numerous small problems initially but now runs efficiently, producing around 10Mwh annually.

Figure 18: Wind Turbine at Casey Station (AAD, 2006)

Wind power has been identified as the most suitable renewable energy option for Scott Base. The average recorded wind speed at the base is reasonably low, with an annual average of 5m/s. The average power produced from a 300kW turbine rated at 12m/s has been determined to be 37.4kW (12.5% of the rated capacity) based on January 2003 Scott Base wind data (Hume *et al*., 2004). Power output in winter will be higher as winter winds are stronger but the output will still be quite low, leading to the conclusion that an alternative site with a higher average wind speed is required to ensure wind energy is an efficient source of power for the base. Meridian Energy has installed a 20m tower at a site above Scott Base in an effort to investigate the best location for a wind turbine. The economics and costs of this wind system have not yet been determined.

Obviously there is considerable potential for the application of wind power in Antarctica, but further technological advances need to be made to ensure that turbines can survive the extreme Antarctic conditions. The reduction in fuel resulting from the use of a wind turbine depends on a number of variables, the main ones being the size of the turbine(s), the characteristics of the site, and the load characteristics of the station. Although it would be possible for a wind turbine to provide the majority of a station's electrical energy requirements, another source of energy generation would still be required for windless or low wind days.

Solar Energy Generation

Solar energy comes in two forms – active solar energy and passive solar energy. Active solar energy utilises technologies such as photovoltaic cells to convert solar radiation into energy, whereas passive solar energy converts solar radiation directly into useful energy.

Photovoltaic cells were developed during the 1950s to provide a lightweight power generation source for the space program satellites (COMNAP, 2005). Over the past few decades, photovoltaic technology has increased rapidly and is now used globally in a number of power generation applications.

Figure 19 shows the average monthly global radiation at Scott Base over 1997-2003, illustrating the high seasonal variability with 0W/m^2 during winter and over 300W/m^2 in December (Hume *et al*., 2004). The consequence of this is that solar energy is inadequate for year round applications in Antarctica, but can be used during the summer months when there is 24 hours of sunlight.

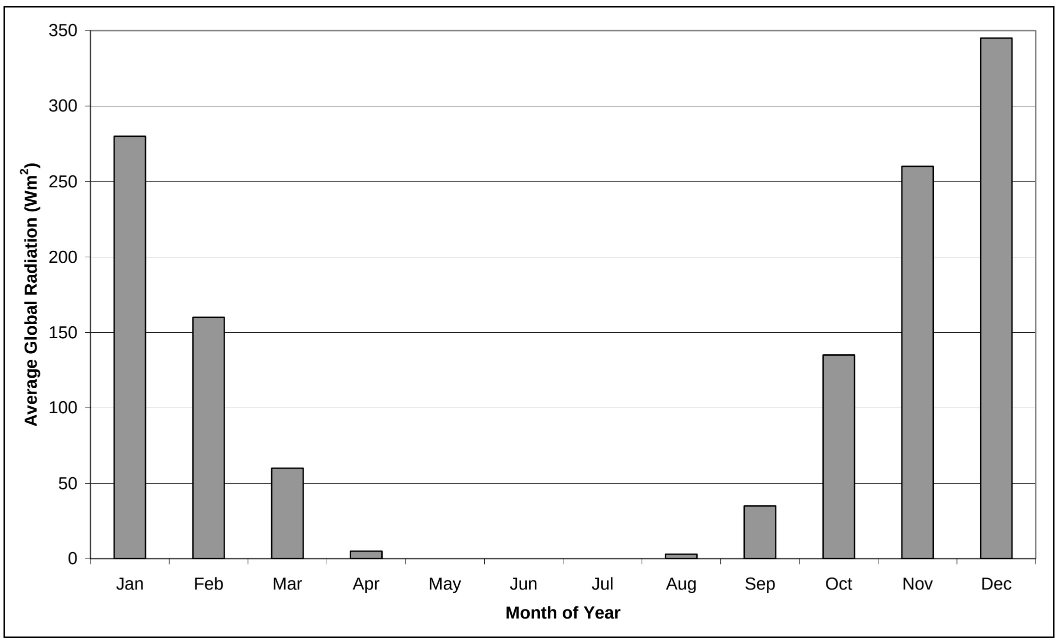


Figure 19: Average Monthly Global Radiation at Scott Base

Photovoltaic panels convert solar radiation into direct current electricity with a typical efficiency of around 10% and cost around \$1000/m^2 (NZD) so from Figure 19, it is possible to determine that the maximum electrical power over December will be approximately 34.5W/m^2, and the annual average will be around 10.6W/m^2 (Hume *et al*., 2004). For this reason, photovoltaic panels are generally limited to small field camps and field stations. The panels are often combined with small wind turbines to ensure more continuous power.

A field camp using solar power successfully is the USAP camp Lake Hoare in the McMurdo Dry Valleys. Lake Hoare is the base for many research activities, and houses up to 16 people at a time. The electricity needs of the camp were previously met with diesel generators but in 1992 a solar array was installed. The camp is now powered by a 1.5kW manually tracked solar array connected to a 4kW inverter with ten 12V, 100 amp hour batteries. The manual tracking ensures the array continually follows the sun. If there is not enough solar energy available and the batteries get depleted, a backup diesel generator powers the camp as it recharges the batteries. The batteries are generally charged after three hours of running the generator and then the solar array powers the camp again. The diesel generator is now reported to run for less than 30 hours each season (USAP, 2005).

On a large scale, photovoltaics are not currently practical in Antarctica due to the cost and the ground area required (Guichard, 2000). A 100kW wind turbine will use around 5m^2 of ground area, but to obtain the same power with photovoltaic panels, thousands of square metres of panels would be required, using a large amount of ground area and increasing the cost significantly. However, there are several new photovoltaic technologies emerging that promise greater efficiency gains and cost reductions so large-scale uses may become more practical in the future.

Passive solar energy is another application of solar radiation in Antarctica, used to provide thermal energy. Solar heating collectors have existed for centuries in various forms and the latest generation of solar hot water collectors have proved effective in Antarctica for summer applications. This technology is reliable, efficient and relatively inexpensive. Different types of air heating collectors have also been trialled in Antarctica and have potential applications (COMNAP, 2005).

A joint research project between the Australian Antarctic Division (AAD) and Latitude Technologies in 1999 investigated the feasibility of heating and supplying the hot water requirements of an Antarctic station during the summer months. A standard Solahart solar hot water system was installed at the Australian Davis Station, and has been operational for the past two years. The system is currently supplying one hundred percent of the hot water for personal ablutions and laundry use in the summer ablutions block (AAD, 2006). There were 83 summer staff during the 2004/05 season at Davis so this is a significant energy saving.

Figure 20: Davis Hot Water System Solar Panels (AAD, 2006)

Another example of passive solar energy use in Antarctica is passive solar hut design. A USAP sea ice camp incorporated passive solar design into their laboratory hut over the 2004-2005 season, resulting in a reduction in the amount of fuel required to heat the hut.

Figure 21: USAP Sea Ice Camp, showing solar panel and arched passive solar hut (USAP, 2005)

As well as using passive solar energy, the research equipment used in the USAP sea ice camp was powered by a hybrid power sled capable of providing 4kW of electricity using a combination of sun and wind, as well as a gasoline generator. The system had a large battery bank to store power and during the 2004/05 season, the gasoline generator was only used twice to charge the batteries for four hours - solar and wind energy supplied electricity for the remainder of the field season.

Solar radiation is undoubtedly a useful energy source in Antarctica, but it can only ever be a supplementary source because it cannot be used year round. Although photovoltaics are currently not practical on a large scale, the use of solar thermal energy for hot water systems and heating can result in significant reductions in fuel usage.

Hydrogen Fuel Cells

A technology that appears to offer considerable promise for future Antarctic power generation is hydrogen fuel cells. Fuel cells use an electro-chemical process to generate electricity with virtually no pollution.

Hydrogen gas can be extracted from water through electrolysis and renewable energy can be achieved by using either wind or photovoltaics to produce the electricity required for the electrolysis. In periods of low wind or solar radiation, the oxygen and hydrogen can then be recombined in a fuel cell to generate electricity.

The core of a fuel cell consists of two electrodes (the anode and the cathode) placed between two flow-field plates (refer Figure 22). The electrodes are each coated on one side with a thin catalyst layer and separated by a proton exchange membrane. Flow-field plates direct hydrogen to the anode and oxygen from the air to the cathode. When the hydrogen reaches the catalyst layer, it separates into protons (hydrogen ions) and electrons. The free electrons produced at the anode act as a usable electric current through the external circuit. At the cathode, oxygen from the air, electrons from the external circuit and protons combine to form water and heat (Ballard Power Systems, 2006).

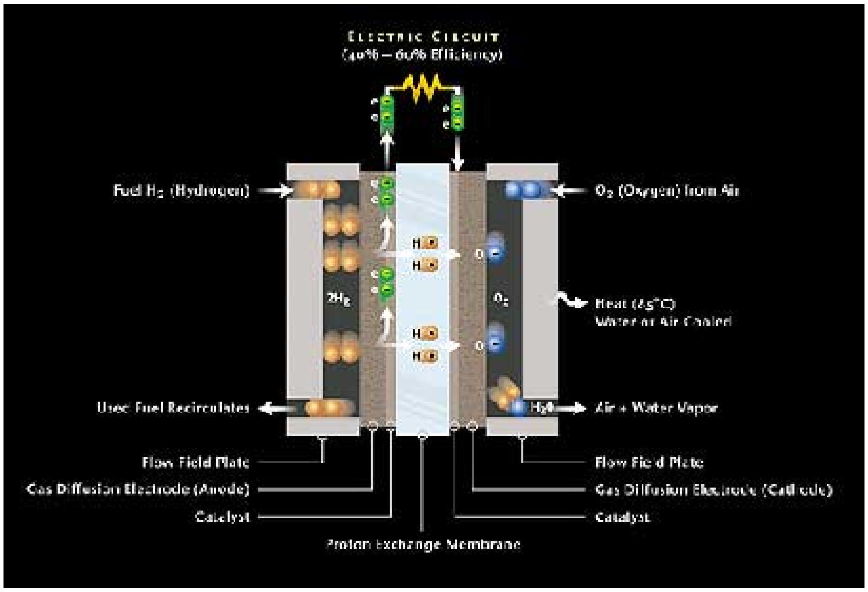


Figure 22: Diagram of a Fuel Cell (Ballard Power Systems, 2006)

The ice cover of Antarctica provides an abundant source of freshwater and for this reason researchers believe it is the perfect testing environment for hydrogen power. Both water and hydrogen can be stored for long periods of time, meaning surplus power could be stored during the winter and then used during the summer when wind resources are lower and wind power might not be available.

An investigation into the use of hydrogen fuel cells occurred at Maitri, the Indian Scientific Research Station in Antarctica in 2002. Three 500W, 12V, fuel cell power sources were prototyped and a series of scientific experiments were conducted to determine the best design of the fuel cell for cold region application. The study concluded by proposing a hybrid power plant for Antarctica taking into account the use of wind energy, generation of hydrogen by an electrolyser and provision of hydrogen storage (Datta *et al*., 2002).

Most recently, the AAD received a grant of $0.5 million (AUD) from the Australian Greenhouse Office to demonstrate the use of hydrogen fuel cells in Antarctica. The project is taking place at the Mawson station during the 2005/06 season and hydrogen will be generated using energy from the Mawson wind turbines, then stored and used in a test fuel cell, as fuel in a heater and in one of the station vehicles. The test fuel cell and heater will then be installed at a field camp on Bechervaise Island, providing the electricity and heat requirements of the camp (Magill *et al*., 2004).

Fuel cells are currently being used commercially in small-scale power plants and in vehicles. The use of fuel cells for large-scale power generation is not yet economically viable but it is hoped that this situation will change by the end of this decade, opening up opportunities for fuel cell usage in Antarctica.

Antarctic Alternative Energy System Case Study

Alternative or renewable energy systems have several benefits over conventional fossil fuel based energy systems in Antarctica. Greenhouse gas emissions are greatly reduced, along with fuel usage, minimising the possibility of fuel spills and the reliance on imported costly fuels.

However, the conversion from fossil fuel energy to renewable energy requires a significant capital investment and even if the outcome is a cost saving, it can be a challenge to make the conversion quickly. Incorporating passive solar design into existing research huts is time and labour intensive, and new research huts are built infrequently. Converting stations to renewable energy presents a number of challenges and the feasibility of large-scale renewable energy systems is still being assessed.

Australia is the first nation to attempt large-scale renewable energy generation in Antarctica. This case study focuses on the Australian Antarctic Division's (AAD) Mawson wind farm, on the east coast of Antarctica, looking at how successful it is from an energy generation, environmental impact and cost perspective.

Project Background

The AAD began investigating the use of renewable energy generation for its Antarctic stations in a joint Australian-French project in 1993. Encouraging results were obtained from the field trial of a 10kW wind turbine at the AAD Casey station (refer to Wind Energy Generation section of this report) and by 1996, research showed that the Mawson station had a suitable wind profile for successful wind energy generation, with an annual average wind speed of 11m/s (Guichard *et al*., 1996). In 1999, a detailed feasibility study indicated that the installation of wind turbines at Mawson would be practical.

In 2001, the AAD formed a consortium with PowerCorp Pty Ltd (a Darwin based contractor) and a German company, Enercon GmbH, to develop and install a wind farm at its Mawson station. An environmental impact assessment was prepared to ensure that the project was consistent with Australia's obligations under the Protocol on Environmental Protection to the Antarctic Treaty and Australian law.

Wind Turbine Installation and Technology Adaptations

Site work for the erection of the wind turbines spanned two summer seasons, with work on the foundations commencing in the 2001/02 summer.

The installation of the wind turbines posed many logistic and construction challenges. These included getting the equipment (which along with the turbine components also included a 50 tonne crane for erecting the turbine towers) across the Southern Ocean, off the vessel and to the erection site at the station. Although a wind farm involving a large number of small turbines would have been easier to install, a lesser number of large turbines was favoured as it was determined that this setup would reduce the number of potential maintenance issues.

The wind turbines themselves were delivered to the station during the 2002/03 summer, and two (of three) 300kW Enercon E30 wind turbine generators were erected and commissioned in 5 weeks (AAD, 2006).
As the winds around Mawson are very powerful, the turbines did not need to be mounted as high to catch the winds, as occurs with turbines in other countries. The Mawson turbine towers are 33m high, and to ensure stability, 64 3m deep ground anchors and 80m^3 concrete foundations were used (Pyper, 2003).

In an effort to prevent bird-strike i.e. birds colliding with the turbines, a free-standing tower was used, rather than a guyed tower. Research performed had shown that birds ran into guy wires on radio towers rather than turbine towers or blades.

The wind turbine was modified to suit the Antarctic conditions in a number of ways. Metal fatigues faster in very cold temperatures (temperatures at Mawson reach -36°C), so the tower and turbine components were made of low temperature steel.

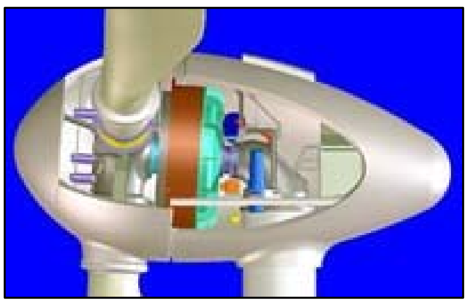


Figure 23: Nacelle of Modified E30 Turbine (AAD, 2006)

Working parts behind the blades (the ‘nacelle’, refer Figure 23) were insulated to preserve some of the mechanically generated heat. Other modifications included not using a gearbox (no oil-leaks due to seal problems in the cold), variable pitch blade mechanism to allow easy control of power output, and good sealing to prevent snow build up. Blade icing is not an issue due to the dry atmosphere at Mawson, and the turbines can safely operate at up to 125 km/h (Australian Business Council for Sustainable Energy, 2003).

PowerCorp developed and installed a system to control and optimize the output of the wind turbines and remaining diesel generators to match the station electrical load. AAD teams erected the turbines, poured the concrete foundations and installed the infrastructure and cabling.

Figure 24: Installing the Mawson Wind Turbine Blades (AAD, 2006)

Wind Farm Energy Generation

The installation and commissioning of the first of two wind turbines was completed in 2003, giving the station a total wind generation capacity of 600kW, along with a total diesel generation capacity of 480kW (AAD, 2006).

The Mawson station’s electrical load is generally between 230-260kW at any time, and the heat load varies from an estimated amount of 240kW in summer to significantly more in winter. The average energy load is approximately 530kW (Paterson, 2001).

The wind turbine system, connected to the station’s 415V ring-main grid, is expected to produce 4.2GWh of electricity per annum and in the first month of operation, the plant generated 116MWh limited to 80% of the station load, with 65% on average (Australian Business Council for Sustainable Energy, 2003).

In combination with the diesel generators running at one-third capacity, the turbines are currently supplying 65% of the station’s needs. The latest published data from the AAD shows that for the month of January 2006, 142MWh of wind power was generated.

The addition of the third turbine in the near future will expand the wind generator capacity to 900kW. With this additional turbine, wind power should be able to supply 100% of the station‘s energy needs for around 75% of the year (AAD, 2006). As discussed within the Hydrogen Fuel Cells section of this report, a grant from the Australian Greenhouse Office is giving the AAD an opportunity to investigate the feasibility of generating hydrogen on site with excess energy from the wind turbines. The hydrogen would be stored in fuel cells and used to power Mawson during low wind periods. If this technology is successful, the Mawson station would be able to meet all of its non-transport energy needs renewably.

Wind Farm Environmental Impact

Before the installation of the wind farm, 700,000 litres of diesel fuel, on average, was required to meet Mawson Station's energy needs, producing approximately 2,000 tonnes of CO_2. In its first year of operation, the wind farm reduced diesel consumption by 27% i.e. the equivalent of 140,000 litres of fuel was saved (DEH, 2004).

The latest published data from AAD shows that for the month of January 2006, the equivalent of 17,078 litres of fuel was saved, resulting in an equivalent saving of 45 tonnes of CO_2. It is expected that CO_2 greenhouse gas emissions will fall by about 600 tonnes annually, benefiting the environment directly. If the wind farm capacity increases as expected, further reductions in fuel and greenhouse emissions are predicted.

The reduction in fuel use will reduce the risk of spills during the annual transport of fuel from Australia to Mawson as refuelling is likely to occur every four-five years, rather than annually (Pyper, 2003). This will lead to economic savings as well as a reduction in the environmental impact.

Wind Farm Costs

The capital cost of the wind farm project was $6.4 million (AUD). The project was entirely internally funded by the AAD and approval to proceed was based solely on its economic viability, primarily in terms of fuel cost savings.

The pay-back period in terms of fuel and infrastructure savings is expected to be within 10 years (AAD, 2006).

An additional cost benefit for the project has been achieved through Renewable Energy Certificates (RECs). RECs are a new form of currency brought in by the Australian Government to create incentives for energy generators to reduce their greenhouse gas emissions. Electricity retailers and buyers must source an additional 9,500GWh of their electricity per year from renewable sources by 2010. Owners of renewable energy systems can trade their RECs to other electricity retailers.

The RECs earned by the Mawson wind turbines have been bought by the Westpac Banking Corporation, helping to offset the cost of the wind turbine project. These RECs will be used to help build new renewable energy capability in the Antarctic and Australia. The agreement with Westpac sees the forward sale of 1,000 RECs a year for the next decade (DEH, 2003).

Case Study Conclusions

The Mawson wind farm appears to have been successful from all perspectives considered. It generates a large proportion of the Mawson station energy requirements, leading to the future possibility of complete independence from fossil fuels. The wind farm's contribution to the energy requirements of the station has significantly reduced the fuel usage, lessening the environmental impact of the station. Finally, the costs involved with setting up the wind farm will be recouped within 10 years of its commissioning, making it a good investment.

The Mawson wind farm illustrates that large-scale wind generation is possible in Antarctica, and will hopefully encourage other nations with bases in Antarctica to investigate the use of renewable energy generation.

Conclusions

Fossil fuels are still the predominant source of power generation in Antarctica. Almost all of the energy needs of New Zealand's main Antarctic research facility, Scott Base, are produced through the burning of fossil fuels.

As well as the atmospheric pollution produced by the burning of fossil fuels, there are serious environmental risks involved with transporting, distributing and storing fuels in the Antarctic. The United States Antarctic Program (USAP) annually delivers fuel by tanker to McMurdo Station and the fuel is then transferred to its required locations, including to Scott Base. Fuel spills are a potential risk at all stages of this process. Fuel re-supply has become more hazardous over recent years due to heavy ice conditions, leading to the conclusion that the current re-supply system is no longer practical. Future re-supply options are currently being considered.

The price of fuel in Antarctica is driven by the original fuel price and the costs associated with fuel re-supply. Political and economic influences lead to severe fluctuations in the price and availability of fossil fuels, but the long term trend appears to be an increase in fuel price. As it becomes more difficult to ship fuel to the Antarctic, the fuel re-supply costs will rise in response. The combination of these factors has lead to an overall increase in the Scott Base fuel costs. Further cost increases may occur if the New Zealand dollar drops as predicted.

All of these issues highlight the importance of reducing energy and fuel usage in Antarctica and significant reductions can be achieved through the implementation of simple energy efficient practices. Recent energy efficiency initiatives at Scott Base have resulted in a decrease in electricity production and fuel usage, with the 2004/05 season fuel usage being the lowest since 2000, despite increasing numbers of field events and base personnel. However, substantial fuel usage would still occur even if the Scott Base energy system was 100% efficient, leading to the conclusion that renewable energy is the only means by which complete independence from fossil fuels will be achieved.

Wind and solar radiation are obvious potential sources of renewable energy in Antarctica, but hydrogen fuel cells also show promise.

Wind turbines are used in a number of small applications around Antarctica but very few large-scale applications have been able to survive the harsh Antarctic conditions. However, Australia's Mawson station on the east coast of Antarctica has shown that large-scale wind generation is possible and is economically viable. The wind farm generates a large proportion of the station's energy requirements, resulting in a significant reduction in fuel. Wind power has been identified as the most suitable form of renewable energy for Scott Base and investigations into the best possible site for a wind turbine are currently in progress.

Solar radiation is a very useful energy source in Antarctica, but it can only ever be a supplementary source due to the lack of sunlight during winter.

The use of fuel cells for large-scale power generation is not yet economically viable but investigations into the application of fuel cells may open up future opportunities for fuel cell use in Antarctica.

References

1. Antarctica New Zealand, 2005, *Energy/Fuel Saving* Report. Information retrieved via email from Julian Tangaere, Antarctica New Zealand, 10/01/2006.

2. Antarctica New Zealand, 2005, *Sustained Improvement in Energy Efficiency.* Information retrieved via email from Julian Tangaere, Antarctica New Zealand, 10/01/2006.

3. Antarctica New Zealand, 2006, *Scott Base Fuel*. Online information retrieved from World Wide Web, 20/01/2006: http://www.antarcticanz.govt.nz/article/4028.html#5061.

4. Antarctica New Zealand, 2006, *Fuel Price History*. Information retrieved via email from Julian Tangaere, Antarctica New Zealand, 20/01/2006.

5. Australian Antarctic Division, 2006, *Harnessing the Power of the Windiest Continent*. Online information retrieved from World Wide Web, 31/01/2006: http://www.aad.gov.au/default.asp?casid=2040.

6. Australian Antarctic Division, 2006, *Solar Powered Hot Water*. Online information retrieved from World Wide Web, 31/01/2006: http://www.aad.gov.au/default.asp?casid=2651.

7. Australian Antarctic Division, 2006, *Renewable Energy*. Online information retrieved from World Wide Web, 02/02/2006: http://www.aad.gov.au/default.asp?casid=396.

8. Australian Business Council for Sustainable Energy, 2003, Mawson Wind Farm, *EcoGeneration Magazine*, June/July 2003.

9. Australian Government Department of the Environment and Heritage (DEH), 2004, *Triple Bottom Line Report 2003-04*. Online report retrieved from World Wide Web, 02/02/2006: http://www.deh.gov.au/about/publications/tbl/03-04/aad.html#fosfue.

10. Australian Government Department of the Environment and Heritage (DEH), 2003, *Energy in the Antarctic*. Media release retrieved from World Wide Web, 02/02/2006: http://www.deh.gov.au/minister/ps/2003/psmr23sep03.html.

11. Ballard Power Systems, 2006, *Fuel Cell Technology*. Online information retrieved from World Wide Web, 01/06/2006: http://www.ballard.com/be_informed/fuel_cell_technology.

12. Bennett, A., 2006, Exchange rate outs heat on NZ petrol prices, *NZHerald.co.nz*. Online information retrieved from World Wide Web, 29/01/2006: http://www.nzherald.co.nz/topic/story.cfm?c_id=1500966&ObjectID=10362456.

13. Council of Managers of National Antarctic Programs (COMNAP), 1992, *Recommendations for Spill Prevention and Containments of Fuel Oil at Stations and Bases.*

14. Council of Managers of National Antarctic Programs (COMNAP), 2005, *Energy Management*. Online information retrieved from World Wide Web, 06/10/2005: http://www.comnap.aq/comnap/comnap.nsf/P/Pages/Operations.ENMANET.

15. Datta, B.K., Velayutham, G. & Prasad Goud, A., 2002, Fuel Cell Power Source for Cold Regions, *Journal of Power Sources* **106** pp 370-376.

16. Grange, E., 2004, *Antarctic Bases: Building Materials, Methods and Design*. 2003/04 GCAS Literature Review.

17. Guichard, A., Magill, P., Godon, P., Lyons, D., & Brown, C., 1996, *Potential for Significant Wind Power Generation at Antarctic Stations*. Paper presented at the Seventh Symposium on Antarctic and Logistics Operations (SCALOP), Cambridge, United Kingdom, 6-7 August 1996.

18. Guichard, A., 2000, *Antarctic Renewable Energy.* National Radio interview transcript retrieved from World Wide Web, 14/06/2005: http://www.abc.net.au/rn/science/earth/stories/s99156.htm.

19. Hume, D. & Bodger, P., 2004, *Renewable Energy for Scott Base. A Win-Win Situation*, Electric Power Engineering Centre, Department of Electrical and Computer Engineering, University of Canterbury, New Zealand.

20. Hume, D., 2005, *Scott Base Energy Audit – Event K424*, Electric Power Engineering Centre, Electrical and Computer Engineering Department, University of Canterbury, New Zealand.

21. International Energy Agency, 2006, *Oil Market Report*. Online report retrieved from World Wide Web, 29/01/2006: http://omrpublic.iea.org.

22. Magill, P. & Rushton, A., 2004, Hydrogen Generated by Antarctic Winds, *Renewable Energy Access*, 29 November 2004.

23. Marschoff, C.M., 1998, Transition from Non-Renewable to Renewable Energy Sources: Fuel Cells in Antarctica as an Economically Attractive Niche, *International Journal Hydrogen Energy* **23:4** pp 303 – 306.

24. National Science Foundation, 1995, *Marine Fuel Spill Response: A Case Study in Polar Waters.* Online report retrieved from World Wide Web, 31/01/06: http://www.nsf.gov/pubs/1996/nstc96rp/sb12.htm.

25. National Science Foundation, 2005, *Ice Breakers Clear Channel into McMurdo Station*. Press release retrieved from World Wide Web, 29/01/06: http://www.nsf.goc/news/news_summ.jsp?cntn_id=100849&org=NSF&from=news.

26. National Science Foundation, 2005, *Report of the Office of Polar Programs Advisory Committee Subcommittee on U.S. Antarctic Program Resupply*. Online report retrieved from World Wide Web, 29/01/2006: http://www.nsf.gov/od/opp/opp_advisory/final_report/oac_resupply_report_081205.pdf.

27. National Science Foundation Office of Polar Programs Advisory Committee (OPP), 2005, *US Antarctic Program Resupply*. Letter retrieved via email from Bryan Storey, Gateway Antarctica, 12/01/2006.

28. National Science Foundation, 2005, *Renewable Energy Use at Field Camps in Antarctica.* Paper presented to the Stockholm Antarctic Treaty Consultative Meeting, 2005.

29. Paterson, C., 2001, *Looking South: Managing Technology, Opportunities and Environment*. Paper presented at the Australian Academy of Technological Sciences and Engineering Symposium, November 2001.

30. Pyper, W., 2003, Extreme Power, *Ecos* **116** pp 8-9.

31. Rahman, M., 2004, The Oil Market Outlook, *Scandinavian Oil-Gas Magazine Online*. Online information retrieved from World Wide Web, 29/01/2006: http://www.scandoil.com/moxie_issue/issue_11-12/the-oil-market-outlook.shtml.

32. Rigarlsford, K., 2003, *Fuel and Energy Trends*. Antarctica New Zealand, New Zealand.

33. Rigarlsford, K., 2006, *Fuel Data 04_05*. Information retrieved via email from Kevin Rigarlsford, 27/01/2006.

34. Rigarlsford, K., 2006, *Fuel Data 03_04*. Information retrieved via email from Kevin Rigarlsford, 31/01/2006.

35. TheTipsBank.com, 2006, *Conversion Formulae*. Online information retrieved from World Wide Web, 27/01/2006: http://www.thetipsbank.com/convert.htm.

36. Walsh, P., 2000, *Keeping Warm: Energy Sources for Scott Base*. 2000/01 GCAS Literature Review.

37. XE.com, 2006, *Currency Converter*. Online information retrieved from World Wide Web, 27/01/2006: http://www.xe.com.